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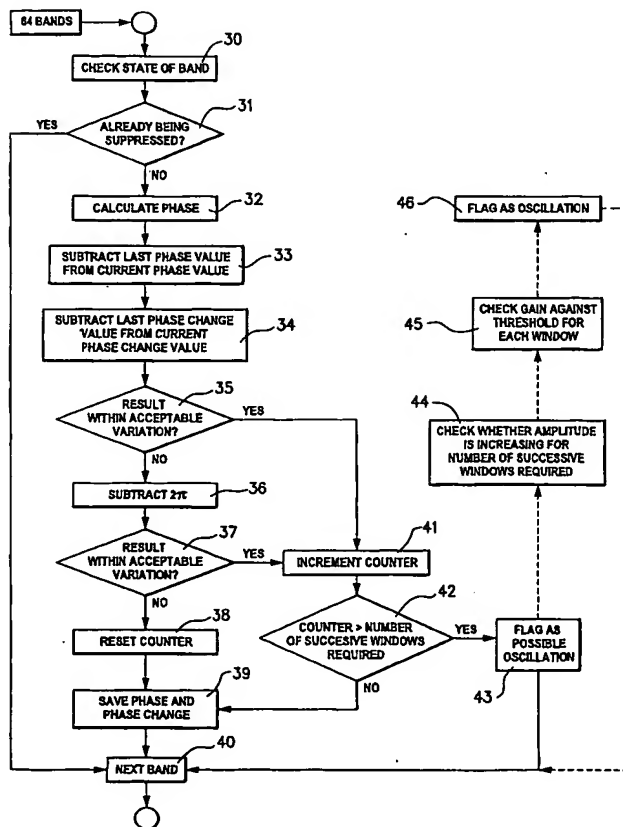
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(54) Title: OSCILLATION DETECTION



(57) Abstract: The invention relates to oscillation detection and, more particularly, concerns a method and apparatus for identifying oscillation in a signal due to feedback, permitting appropriate action to be taken to suppress the oscillation. The method involves using an FFT device or similar to convert a signal at each of a series of successive time windows into the frequency domain, calculating, for each of a plurality of frequency bands, the change in signal phase from a time window to a subsequent time window, and comparing, for some or all of said frequency bands, the results of the calculation step to one or more defined criteria to provide a measure of whether oscillation due to feedback is present in the signal. For additional discrimination, the change in signal amplitude from a time window to a subsequent time window may also be calculated for each of the frequency bands, and the result compared with one or more further defined criteria. The invention has particular application in hearing aid devices.

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OSCILLATION DETECTION

Field of the Invention

The present invention relates to oscillation detection and, more particularly, concerns a method and apparatus for identifying oscillation in a signal due to feedback. The present invention may be used in conjunction with the method and apparatus for suppressing oscillation in a signal described in applicant's copending international application entitled 'Oscillation Suppression', based on Australian provisional patent application AU-2003902587.

Background of the invention

In this specification, where a document, act or item of knowledge is referred to or discussed, this reference or discussion is not an admission that the document, act or item of knowledge or any combination thereof was, at the priority date, part of common general knowledge, or known to be relevant to an attempt to solve any problem with which this specification is concerned.

Acoustic amplifiers are used in many common applications such as telephones, radios, headsets, hearing aids, and public address systems. Typically, such an application comprises a microphone or other input transducer to pick up sounds and convert them into an electrical signal, an electronic amplifier to increase the power of the electrical signal, and a speaker or other output transducer to convert the amplified electrical signal back into sound.

If the input and output transducers are close enough, the output acoustic signal may be picked up by the input transducer and fed back into the amplifier with a delay, the delay being the time taken for the sound to travel from the output transducer to the input transducer (plus any delay due to the electrical processing of the signal). This is 'acoustic feedback'. Electrical feedback can also occur if the electrical signal at the output is coupled back to the input, for example by inductive or capacitive coupling. Further, mechanical feedback can also occur if vibrations are transmitted from the output transducer to the input transducer via the body or case of the amplification system.

Under feedback conditions, the device can then become unstable and the components begin to ring. The ringing then self-reinforces and increases in intensity to drive the components into saturation. Figure 1 illustrates a feedback loop, showing diagrammatically the components in an acoustic amplifier circuit, namely microphone 1,

amplifier 2 and speaker 3, with feedback loop 4 representing the output signal feeding back to the input transducer.

All forms of feedback may result in instability or oscillation of the output signal from the amplifier under certain conditions. Oscillation and instability are undesirable because they distort the signals being amplified and can result in very loud unpleasant sounds. In the case of hearing aids, this can lead to problems both for the wearer and for those around. The conditions for oscillation are that the total gain around the loop must be greater than 1, so that the signal is fed back into the system with a greater intensity each time, and the total delay around the loop must be a whole number of periods of the oscillation frequency, so that the input and output signals add constructively. Equivalently, the total phase change around the loop must be a multiple of 2π radians for the oscillation frequency. These criteria are set out in equations 1 to 3 below.

$$\text{Loop Gain} > 1 \quad (\text{eq. 1})$$

$$\text{Loop Delay} = N \times \text{period} \quad (\text{eq. 2})$$

$$\text{Loop Phase Change} = 2N\pi \text{ radians} \quad (\text{eq. 3})$$

(where N is a positive integer)

Any electronic system containing a microphone and speaker in close proximity may suffer from acoustic feedback. In hearing aids, this often results in the wearer experiencing unpleasant audible effects such as loud whistling tones at certain frequencies, usually high frequencies.

The traditional procedure for increasing the stability of a hearing aid is to reduce the gain at high frequencies, as suggested in, for example, US Patent 4,689,818. This may be done by setting the maximum gain value for each frequency, or automatic high frequency (HF) gain roll-off may be used. Controlling feedback by modifying the system frequency response, however, means that the desired high-frequency response of the instrument must be sacrificed in order to maintain stability.

Efforts have been undertaken to reduce the susceptibility of hearing aids to feedback oscillation by improving the fit and insulating properties of the ear mould. Efforts have also been undertaken from an electrical standpoint, from attenuation and notch filtering, as disclosed in US Patent 4,088,835, to estimation and subtraction of the feedback signal, as disclosed in US Patent 5,016,280, to frequency shifting or delaying the signal, as disclosed in US Patent 5,091,952. Many different approaches to an electrical solution

with continuous monitoring of the feedback path have been documented in the relevant literature.

A technique commonly used to suppress feedback in public address systems is a frequency shift, in which the input signal is altered by a few Hertz prior to being output at the receiver. This approach has not been particularly successful in hearing aids because a large frequency shift is required to achieve a significant increase in gain. In hearing aids, the distance between microphone and receiver is much smaller than in public address systems, and thus a feedback signal with only a small frequency shift may still be relatively closely in phase with the input.

Signal phase can also be altered by using a time-varying delay [1]. While this can provide 1-2dB of additional useable gain, it can also result in an audible 'warbling' effect. All pass filters have also been used to modify the phase response of the feedback loop, but it can be difficult to achieve satisfactory phase at all frequencies. Methods have been proposed to push danger regions in the phase response to frequencies outside the primary audio range where suppression can be applied without loss of sound quality [2] [3]. These techniques still assume that the feedback path is constant however, and no suggestion has been made that an adaptive implementation may be developed.

The most common gain altering approaches attempt to reduce the system gain only in narrow bands where feedback is likely to occur. This has been attempted with a variety of notch filter implementations [1] [4] [5]. Adaptive notch filtering has allowed 3-5 dB of additional useable gain. Two of the biggest problems with notch filtering techniques have been the inability to accurately track the variations in the feedback path with a narrow band, and the effects on normal spectral content with a broader band. In addition, the notch filter can actually contribute an additional phase change to the loop and shift the frequency of oscillation as soon as it is applied.

Substantial increases in useable gain have been achieved by inserting an additional feedback path, based on an estimation of the real feedback path, but 180 degrees out of phase. Early adaptive implementations of such systems performed continuous estimation of the feedback path by inserting noise signals with appropriate statistical properties at the receiver and correlating the output with the input at the microphone [1] [6]. These reported up to 10 dB of additional useable gain [7] but, since the noise 'test' signals were audible and unpleasant for most wearers, this particular technique never became particularly widespread.

More recent feedback cancellation systems of this type rely on sounds in the environment to perform their correlation [8]. To avoid artefacts and incorrect suppression of speech however, the estimation time has to be longer than in systems using unnatural sounds to perform correlation. This means that sudden changes in the feedback path can result in several seconds of whistling before successful cancellation occurs. If implemented in conjunction with another technique to handle sudden changes, this approach can allow at least 10dB of additional useable gain [9]. The benefits and limitations of such systems are discussed in [10].

Nearly all of the techniques discussed here require some knowledge of the frequency of oscillation. However, as a result of the nature of direct and multiple reflected acoustical paths between microphone and speaker (or the changing acoustic properties of the ear/earmould/hearing aid coupling with regard to hearing aids) the frequency of acoustic feedback is unpredictable and may extend over a substantial portion of the audio frequency spectrum (between 20 and 20,000 Hz). As a result, it is desirable to have a circuit that can quickly identify an oscillation and its frequency.

US Patents 4,232,192 and 4,079,199 propose systems using a phase locked loop (PLL) adapted to recognize an oscillation when it occurs. As is known, however, when the input signal falls off, a PLL tends to become unstable and to drift. The result of the drift is an undesirable periodic, acoustic noise signal.

US Patent 4,845,757 describes another oscillation recognition circuit. This circuit detects oscillations by looking for long-lasting alternating voltages having relatively large amplitude and relatively high frequency. This is problematic in many applications because it means that the signal may contain feedback oscillations for some time before they are identified by such a circuit.

There remains a need in the art to provide an improved or at least an alternative way of detecting oscillations in a signal in a reliable, effective and rapid manner, and to apply appropriate suppression to the signal upon detection.

SUMMARY OF THE INVENTION

The invention provides, in accordance with a first aspect, a method of identifying oscillation in a signal due to feedback, the method comprising the steps of:

converting the signal at each of a series of successive time windows into the frequency domain;

calculating for each of a plurality of frequency bands the change in signal phase from a time window to a subsequent time window; and

comparing, for some or all of said frequency bands, the results of the calculation step to one or more defined criteria to provide a measure of whether oscillation due to feedback is present in the signal.

This affords a technique for automatically monitoring whether the change in phase over time in a frequency band is sufficiently constant to indicate the presence of an oscillation in the signal. The successive time windows represent time intervals selected for desired performance, and are preferably of 1-100ms duration. The windows may be discrete, or successive such windows may overlap.

Preferably, the method includes the step of further calculating, for some or all of said frequency bands, the change in signal amplitude from a time window to a subsequent time window, and comparing the result of the further calculation step to one or more further defined criteria, to provide a further measure as to whether oscillation due to feedback is present in the signal. This step can be used to provide an additional level of discrimination.

In one form of this first aspect of the invention, for use in a system involving deriving gain values for said frequency bands in accordance with a specified signal processing algorithm, the method may include the step of comparing, for some or all of said frequency bands, the derived gain with a prescribed gain limit, in order to provide a further measure as to whether oscillation due to feedback is present in the signal.

The derived gain may be compared with said prescribed gain limit only for frequency bands and in time windows in which said one or more defined or further defined criteria is/are met.

The signal conversion into the frequency domain may be carried out by way of a Fast Fourier Transform technique.

In a preferred form, for each frequency band, for each time window, the signal phase from one or more previous time windows is compared with that from the current time window to calculate a change of phase, and this phase change is then compared with a previous phase change to provide a measure of the change in phase change.

Preferably, the signal phase change is calculated from each time window to the next successive time window, to provide a continuous monitoring of the change in phase

change in that frequency band. Alternatively, other approaches may be employed to monitor the phase change over successive time windows, such as a statistical sampling technique.

A counter may be employed, the counter incremented if the value of the change in phase change is within a prescribed limit, the counter being reset if it is not, the measure of whether oscillation due to feedback is present in the signal being provided by the counter reaching a value M_p .

If signal amplitude monitoring is employed, the method may include the step of, for each frequency band, for each time window, comparing the amplitude from at least a previous window with that of the current window to calculate a change in amplitude.

A counter may be employed, the counter being incremented if the value of the amplitude change is greater than zero, the counter being reset if it is not, the further measure of whether oscillation due to feedback is present in the signal being provided by the counter reaching a value M_a .

The value of M_p and/or M_a is selected as appropriate, dependent on the specific application and the level of sensitivity required to achieve the desired performance.

In one form of the invention, M_p is equal to M_a .

Preferably, on determination that oscillation due to feedback is present in the signal, a selected method for suppressing oscillation is applied to the signal in that frequency band.

The suppression technique employed may include the step of adding a random phase to the signal in at least one of said frequency bands for a prescribed period of time.

Alternatively, the suppression technique may be selected from the group of: applying a phase shift; applying a notch filter; subtracting a signal from the input signal; and applying a gain attenuation.

The above-described oscillation detection method may be applied to a feedback management system for a signal processing apparatus incorporating selectively adjustable or settable signal gain values, whereby the steps of comparing, calculating and comparing are carried out as part of a setup phase, in order to set or adjust said gain values.

The invention provides, in accordance with a second aspect, apparatus for identifying oscillation in a signal in a system having an input transducer and an output transducer, comprising:

means for converting the signal into the frequency domain;

means for analysing the converted signal at each of a succession of time windows over a number of frequency bands, to determine the amplitude and phase of the signal in each frequency band;

- 5 means for calculating the change in signal phase for each frequency band from a time window to a subsequent time window; and

means for comparing the change in phase with one or more defined criteria to provide a measure of whether oscillation is present in the signal.

- 10 Preferably, means are included for further calculating, for each of the frequency bands, the change in signal amplitude from one time window to a subsequent time window, and means for comparing the result of the further calculation step to one or more further defined criteria, to provide a further measure as to whether oscillation is present in the signal.

The converting means may comprise a Fast Fourier Transform (FFT) unit.

- 15 The apparatus may include means for comparing, for each frequency band and for each time window, the signal phase from one or more previous time windows with that from the current window to calculate a change of phase, and means for comparing this phase change with a previous phase change to provide a measure of the change in phase change.
- 20 Preferably, the means for comparing is arranged to calculate the signal phase change from each time window to the next successive time window, to provide continuous monitoring of the change in phase change in that frequency band.

- In one form of the invention, a counter is included, arranged to be incremented if the value of the change in phase change is within a prescribed limit, and to be reset if it is not,
- 25 the measure of whether oscillation is present in the signal being provided by the counter reaching a value M_p .

- If means are included for calculating the change in signal amplitude from one time window to a subsequent time window, this may comprise means for comparing, for each frequency band and for each time window, the amplitude from at least one previous
- 30 window with that of the current window, to calculate a change in amplitude.

A counter may be arranged to be incremented if the value of the amplitude change is greater than zero, and to be reset if it is not, the further measure of whether oscillation is present in the signal being provided by the counter reaching a value M_n .

In a preferred form, the apparatus is provided in combination with a means for
5 suppressing oscillation, the suppressing means arranged to be triggered in accordance with the measure of whether oscillation is present in the signal.

The apparatus may include means for reconvertng the signal to a waveform signal to be fed to the output transducer.

The apparatus of the invention may be applied in combination with a system for deriving
10 gain values for said frequency bands in accordance with a specified signal processing algorithm, including means for comparing, for some or all of said frequency bands, the derived gain with a prescribed gain limit, to provide a further measure as to whether oscillation due to feedback is present in the signal.

In this latter form of the invention, means may be included for comparing the derived
15 gain values with said prescribed gain limit only for frequency bands and in time windows in which said one or more defined or further defined criteria is/are met.

In a further form, the invention provides a feedback management system for a signal processing apparatus incorporating selectively adjustable or settable signal gain values, including the above-defined apparatus, the system including means for setting said gain
20 values in accordance with a measure of whether oscillation is present in the signal.

The invention differs from previous techniques because it relies on continuous monitoring of signal phase information as the primary criterion for oscillation detection, thus allowing oscillation conditions to be identified *before* the amplitude of the signal at a particular frequency reaches an undesirable level, ideally before audible ringing occurs.

25 The present invention therefore provides a feedback detection system that continually monitors an input signal and recognises the presence of an oscillation quickly and accurately.

If feedback is detected, a feedback suppression algorithm can be applied, such as alteration of the feedback loop in a manner that disrupts the feedback oscillation
30 conditions and suppresses the oscillation without significantly affecting the system frequency response.

In the preferred method of carrying out the invention, short samples or windows of the input signal are analysed into a number of frequency bands via a Fast Fourier Transform (FFT), the amplitude and phase of each frequency component is calculated and then checked against the following oscillation criteria:

1. The change in phase from one window to the next must be constant within an acceptable small variation for at least M_p successive windows.
2. (Optional) The amplitude of the frequency component should be increasing from one window to the next for at least M_a successive windows.

The invention is based on the realisation that if an oscillation is present in a frequency band it will either dominate the band or be attenuated by destructive interference. Thus any band containing an oscillation that is not attenuated will have a reasonably constant change in phase from one window to the next. In addition, any band that is feeding back to the input will experience an increase in amplitude. By monitoring each frequency band with regards to at least the first of these criteria, the technique can be used to identify oscillation, often before the amplitude becomes uncomfortably loud. In addition, by using these two criteria in conjunction the system can avoid misdiagnosing loud sounds or most oscillating musical tones as feedback.

As will be clear from the above, the technique of the invention can involve checks against three different criteria in determining whether oscillation due to feedback is present in the signal; namely the change in signal phase, the change in signal amplitude, and the derived gain value. It should be noted that each of these checks on the signal may be made in some or all of the frequency bands, and that the checks may be applied in any order to the signal in each frequency band. For example, the gain calculation may be made as an initial check in one or more frequency bands, and if the threshold is not met then the phase change calculation need not be carried out in the relevant frequency band(s) for that time window. The order and logic of applying the different criteria in determining whether oscillation due to feedback is present will depend on the particular application of the invention, and/or on the particular conditions of use.

It should be noted that the feedback detection method may be used with any suitable approach to feedback suppression.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more apparent by describing in detail a preferred non limiting embodiment with reference to the attached drawings, in which:

Fig. 1 is a block diagram schematically illustrating a feedback loop;

Fig. 2 is a block diagram of an apparatus according to the present invention;

Fig. 3 is a flow diagram illustrating the logic and process of feedback detection;

Fig. 4 is a flow diagram illustrating the logic and process of feedback suppression; and

5 Figs. 5 and 6 are block diagrams of alternative architectures of apparatus according to the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An acoustic system 10 in accordance with the invention, such as a hearing aid, is schematically depicted in Figure 2. A microphone 11 converts an acoustic signal, such as the speech, into an analogue electrical signal proportional to the acoustic signal, which
10 signal is then converted by an A/D converter 12 into a digital signal. The output of A/D converter 12 is connected to the input of a Discrete Fourier Transform (DFT) unit – such as a Fast Fourier Transform (FFT) unit 13 - for analysing the frequency components of the signal, whilst unit 14 enables analysis of 64 frequency bands across the spectrum of the
15 signal. A suitable unit is the Toccata Plus integrated circuit designed and developed by the Dspfactory, operating with 16 kHz sampling rate and using 128 point windows of 8 millisecond duration with 50% overlap to yield 64 linearly spaced frequency bands at 125Hz intervals from 0 to 8000 Hz. Module 20 is a feedback detector arranged to monitor the phase and amplitude of the signal in each frequency band in the spectrum (adjusted if
20 appropriate, as explained further below) during successive sampling windows at short intervals, such as successive 8 millisecond windows with 50% overlap, calculated every 4 milliseconds. The apparatus includes a counter for each frequency band, which can be incremented or reset at each successive time window.

For each time window, the measured phase from the previous window is subtracted from
25 the phase in the current window to calculate the change in phase at a particular frequency band. This change in phase is compared to the previous change in phase. If the values are within a defined variation (ie the change in the phase change is within the threshold) then the counter is incremented, otherwise the counter is reset. Further, the amplitude in the current window is compared with the amplitude in the previous window. If the
30 current amplitude is less than the previous amplitude, then the counter is reset. The feedback detector is programmed to respond – by triggering feedback suppression - to the counter reaching a value M. The present invention contemplates that either the change in

phase change criterion (counter reaches M_p) or the change in amplitude criterion (counter reaches M_a) may be considered for suppression triggering, or both.

The example represented in Figure 3 illustrates, for a time window, the process of detection using the change in phase change criterion. For each of the 64 bands, the state of the band is determined (30). If that band is already being suppressed (31), no calculations are performed. Otherwise, the phase is calculated (32), and the previous phase value calculated for that band (which value has been stored – see below) is subtracted from the current phase value (33) to provide a current value of phase change. The next step (34) is to subtract the previous phase change value from the current phase change value, to output a value of change of phase change. This value is then checked (35) and (37), and if it is within a certain prescribed threshold for phase change variation, the counter is incremented by 1 (41). The subtraction of 2π radians (36) and second check (37) ensure that output is dependent on the magnitude of the change of phase change, irrespective of whether the change has increased or decreased. If the value is not within the threshold, the counter is reset to 0 (38), the current phase and phase change value is saved (39), and the next band is selected (40).

The process described above, involving the step of subtracting 2π radians from the value of the change in phase change and re-checking whether the result is within the prescribed threshold (36, 37), can be replaced by an alternative technique. Instead, the full range of the signed fixed-point numbers can be used to represent the angular phase change from $-\pi$ to $+\pi$, meaning that when successive phase change values are subtracted, the result is also in the range $-\pi$ to $+\pi$. This is a standard calculation technique and will not be further described here.

If the counter has been incremented (41), a check is made to determine if it has reached a value M_p (42), thereby indicating an oscillation has been detected (43) and flagging that band for suppression (see below). If not, the current phase and phase change values are saved (39), and the next band is selected (40). It is to be noted that the bands can be checked in parallel or sequentially within each time window.

If the signal in each frequency band is also to be checked for increasing amplitude, the amplitude is monitored from one time window to the next and, if it is increasing over the prescribed number M_a of successive windows, this measure can be applied in determining whether an oscillation is present in the signal in that frequency band (reference 44 in Figure 3).

In simulations carried out by the inventors, where both criteria for detection have been employed, $M_a=M_p=12$ gives good performance. Using $M_a=M_p$ simplifies the detection apparatus and method, as the process can then readily be implemented using a common counter. If only one criterion is to be employed in detecting feedback, the M_a or M_p value
5 may be increased to avoid false triggering of feedback suppression.

Once the counter for any frequency band exceeds the required values of M_a and/or M_p , this frequency band is deemed to be in oscillation, and an oscillation suppression algorithm is implemented (in this example, an 'apply phase' module 21 is triggered – see Figure 2).

Apply phase module 21 generates a complex number with random phase and amplitude
10 1.0 for each window, and multiplies the real gain value at module 22 for the frequency band by this complex number before the gain is applied to the signal via gain unit 23 to provide an adjusted spectrum 24. The loop illustrated in Figure 2 indicates that the phase of the gain multipliers depends on the apply phase unit, which operates in accordance with the output of the feedback detector unit. Apply phase module 21 continues to apply
15 random phase to the gain for a prescribed length of time (for example, around 8 s), to allow the conditions which created the feedback path to change.

The example represented in Figure 4 illustrates the process of suppression for a time window, appropriate for the example embodiments illustrated in Figures 5 and 6. Firstly, the state of a selected band is checked (50), to determine whether it is flagged for
20 suppression (51). If not, the next band is selected (57). If it is flagged for suppression, the magnitude of the signal at that band is obtained (52) and multiplied by the real part of the generated random complex number (53), the resulting new real component being saved (54). Further, the magnitude of the signal is multiplied by the corresponding imaginary part of the generated random complex number (55), and the resulting new
25 imaginary component saved (56).

The signal passes through MPO unit (Maximum Power Output) 25 (see Figure 2), and is then reconverted into a time domain waveform by inverse FFT module 26. A D/A converter 27 then converts the digital signal to an electrical analogue signal before supplying it to the hearing aid output terminal to drive speaker 28.

30 It is to be noted that the 'magnitude of the signal' in a band referred to above in the context of Figure 4 may be the output spectrum value (for the embodiments shown in Figures 5 and 6), or may be the gain value (for the embodiment shown in Figure 2), and the invention may be implemented using either approach, the selection depending at least in part on the hardware employed for the processing. In the alternative

architectures of Figures 5 and 6 the random phase is applied to the output spectrum rather than to the gains, in both embodiments the gain values are applied to the signal by gain unit 23 before feedback detector 20. In Figure 6, MPO unit 25 is omitted, to illustrate that the invention can be implemented without such a component.

5 As will be evident to the skilled reader, it is not necessary to apply feedback detector 20 and oscillation suppression module 21 together. An alternative form of feedback suppression, such as application of a notch filter, may be applied to a signal in which feedback oscillation has been identified by feedback detector 20. Other types of feedback suppression which might be employed include gain attenuation at the frequency band in
10 question, applying a time varying phase change, or subtraction of the signal at the frequency band in question.

It has been found in simulations carried out by the inventors that application of both feedback detector 20, combining the monitoring of both phase change and amplitude, along with the application of apply phase module 21, can result in suppression of all
15 feedback oscillation in 60-100 milliseconds.

As the skilled reader will readily recognise, the method and apparatus of the present invention may be used in combination with other compatible signal processing techniques. For example, the present inventors have successfully incorporated an adaptive dynamic range optimisation (ADRO™) sound processor, of the sort described in
20 International Patent Application WO-00/47014, into a system employing the feedback detection approach of the present invention.

In a system with adaptive gain (such as the ADRO™ processing strategy), feedback is more likely to occur when gains are high. In one form of the present invention, a further criterion is considered by the feedback detection algorithm, namely, for each of the 64
25 frequency bands, a comparison of the gain in each time window with a prescribed threshold level. This step is schematically illustrated by reference 45 in Figure 3, as a factor in determining whether oscillation is present in the signal (46) in the relevant frequency band. In this approach, if both the signal phase criterion (described above) and the gain criterion are satisfied, then it is concluded that feedback is occurring, and
30 feedback suppression is triggered.

This technique has the advantage that the risk of false triggering is reduced. In addition, as this method ensures that feedback will only be detected when gain values are relatively

high, application of a gain reduction suppression technique to suppress the feedback will not reduce the gain to an undesirably low level.

In one implementation embodiment, when employed in combination with an adaptive gain system such as ADRO™, the gain threshold is defined as a fixed number of dB below the maximum limit placed on the gain by the adaptive gain system. This approach can also be taken in other nonlinear or adaptive systems that employ variable gain, such as in so-called 'compression' systems which apply lower gains to loud input signals and higher gains to softer input signals.

The present invention has been described above with reference to an implementation providing real-time feedback detection (eg in use by a hearing aid wearer), in order to trigger real-time suppression measures. However, as the skilled reader will appreciate, the oscillation detection technique of the invention can also be used for feedback management, applied at a setup (or adjustment) phase, in order to set parameters of the signal processing system. The feedback management step is therefore undertaken only once during the setup phase of the amplifying system, or during any subsequent resetting of the apparatus.

In this feedback management process, the feedback detection technique is used to detect the onset of feedback while amplifier gain limits are adjusted during the setup phase.

This serves to remove steady state feedback, whilst the real-time feedback detection/suppression system then operates during normal use of the apparatus to reduce the occurrence of transitory feedback caused by changing environmental conditions.

Modifications and improvements to the invention will be readily apparent to those skilled in the art. Such modifications and improvements are intended to be within the scope of this invention. For example, in accordance with the invention, the signal spectrum may be split into a plurality of discrete frequency bands, or alternatively neighbouring bands may overlap.

The word 'comprising' and forms of the word 'comprising' as used in this description and in the claims does not limit the invention claimed to exclude any variants or additions.

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CLAIMS

1. A method of identifying oscillation in a signal due to feedback, the method comprising the steps of:

converting the signal at each of a series of successive time windows into the
5 frequency domain;

calculating for each of a plurality of frequency bands the change in signal phase from a time window to a subsequent time window; and

comparing, for some or all of said frequency bands, the results of the calculation step to one or more defined criteria to provide a measure of whether oscillation due to
10 feedback is present in the signal.

2. The method of claim 1, including the step of further calculating, for some or all of said frequency bands, the change in signal amplitude from a time window to a subsequent time window, and comparing the result of the further calculation step to one or more further defined criteria, to provide a further measure as to whether oscillation due to
15 feedback is present in the signal.

3. The method of any preceding claim, in which the step of signal conversion into the frequency domain is carried out by way of a Fast Fourier Transform technique.

4. The method of any preceding claim, in which the number of frequency bands is around 64.

5. The method of any preceding claim, in which said successive time windows are in the range of 1 to 100 ms.
20

6. The method of any preceding claim, in which for each of said plurality of frequency bands, for each time window the signal phase from one or more previous time windows is compared with that from the current window to calculate a change of phase, and this phase change is then compared with a previous phase change to provide a
25 measure of the change in phase change.

7. The method of claim 6, in which the signal phase change is calculated from each time window to the next successive time window, to provide a continuous monitoring of the change in phase change in that frequency band.

8. The method of claim 6 or 7, in which a counter is employed, the counter being incremented if the value of the change in phase change is within a prescribed limit, the
30

counter being reset if it is not, the measure of whether oscillation due to feedback is present in the signal being provided by the counter reaching a value M_p .

9. The method of claim 2, in which for each frequency band, for each time window the amplitude from at least one previous window is compared with that of the current window to calculate a change in amplitude.

10. The method of claim 9, in which a counter is employed, the counter being incremented if the value of the amplitude change is greater than zero, the counter being reset if it is not, the further measure of whether oscillation due to feedback is present in the signal being provided by the counter reaching a value M_a .

11. The method of claim 10 insofar as dependent on claim 8, wherein $M_p = M_a$.

12. The method of any preceding claim, in which, on determination that oscillation due to feedback is present in the signal, a selected method for suppressing oscillation is applied to the signal in that frequency band.

13. The method of claim 12 in which the suppression technique includes the step of adding a random phase to the signal in at least one of said frequency bands for a prescribed period of time.

14. The method of claim 12 in which the suppression technique is selected from the group of: applying a phase shift; applying a notch filter; subtracting a signal from the input signal; and applying a gain attenuation.

15. The method of any preceding claim, for use in a system involving deriving gain values for said frequency bands in accordance with a specified signal processing algorithm, including the step of comparing, for some or all of said frequency bands, the derived gain with a prescribed gain limit, in order to provide a further measure as to whether oscillation due to feedback is present in the signal.

16. The method of claim 15, including the step of comparing the derived gain with said prescribed gain limit only for frequency bands and in time windows in which said one or more defined or further defined criteria is/are met.

17. The method of any preceding claim, applied to a feedback management system for a signal processing apparatus incorporating selectively adjustable or settable signal gain values, whereby the steps of comparing, calculating and comparing are carried out as part of a setup phase, in order to set or adjust said gain values.

18. Apparatus for identifying oscillation in a signal in a system having an input transducer and an output transducer, comprising:

means for converting the signal into the frequency domain;

5 means for analysing the converted signal at each of a succession of time windows over a number of frequency bands, to determine the amplitude and phase of the signal in each frequency band;

means for calculating the change in signal phase for each frequency band from a time window to a subsequent time window; and

10 means for comparing the change in phase with one or more defined criteria to provide a measure of whether oscillation is present in the signal.

19. The apparatus of claim 18, including means for further calculating, for some or all of said frequency bands, the change in signal amplitude from one time window to a subsequent time window, and means for comparing the result of the further calculation step to one or more further defined criteria, to provide a further measure as to whether
15 oscillation is present in the signal.

20. The apparatus of claim 18 or 19, wherein the converting means comprises a Fast Fourier Transform (FFT) unit.

21. The apparatus of any one of claims 18 to 20, including means for comparing, for each frequency band and for each time window, the signal phase from one or more
20 previous time windows with that from the current window to calculate a change of phase, and means for comparing this phase change with a previous phase change to provide a measure of the change in phase change.

22. The apparatus of claim 21, wherein said means for comparing is arranged to calculate the signal phase change from each time window to the next successive time
25 window, to provide continuous monitoring of the change in phase change in that frequency band.

23. The apparatus of claim 21 or 22, including a counter arranged to be incremented if the value of the change in phase change is within a prescribed limit, and to be reset if it is not, the measure of whether oscillation is present in the signal being provided by the
30 counter reaching a value M_p .

24. The apparatus of claim 19, in which the means for further calculating comprise means for comparing, for each frequency band and for each time window, the amplitude

from at least one previous window with that of the current window, to calculate a change in amplitude.

25. The apparatus of claim 24, including a counter arranged to be incremented if the value of the amplitude change is greater than zero, and to be reset if it is not, the further
5 measure of whether oscillation is present in the signal being provided by the counter reaching a value M_a .

26. The apparatus of any one of claims 18 to 25, in combination with a means for suppressing oscillation, the suppressing means arranged to be triggered in accordance with the measure of whether oscillation is present in the signal.

10 27. The apparatus of any one of claims 18 to 26, including means for reconvertng the signal to a waveform signal to be fed to the output transducer.

28. The apparatus of any one of claims 18 to 27, in combination with a system for deriving gain values for said frequency bands in accordance with a specified signal processing algorithm, including means for comparing, for some or all of said frequency
15 bands, the derived gain with a prescribed gain limit, to provide a further measure as to whether oscillation due to feedback is present in the signal.

29. The apparatus of claim 28, including means for comparing the derived gain values with said prescribed gain limit only for frequency bands and in time windows in which said one or more defined or further defined criteria is/are met.

20 30. A feedback management system for a signal processing apparatus incorporating selectively adjustable or settable signal gain values, including the apparatus of any one of claims 18 to 29, the system including means for setting or adjusting said gain values in accordance with a measure of whether oscillation is present in the signal.

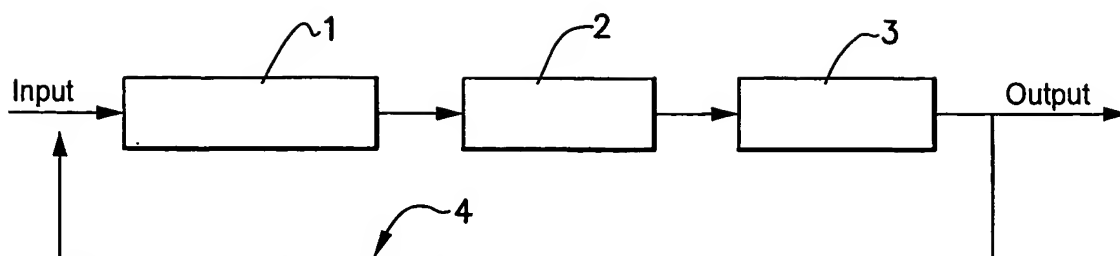


Fig. 1

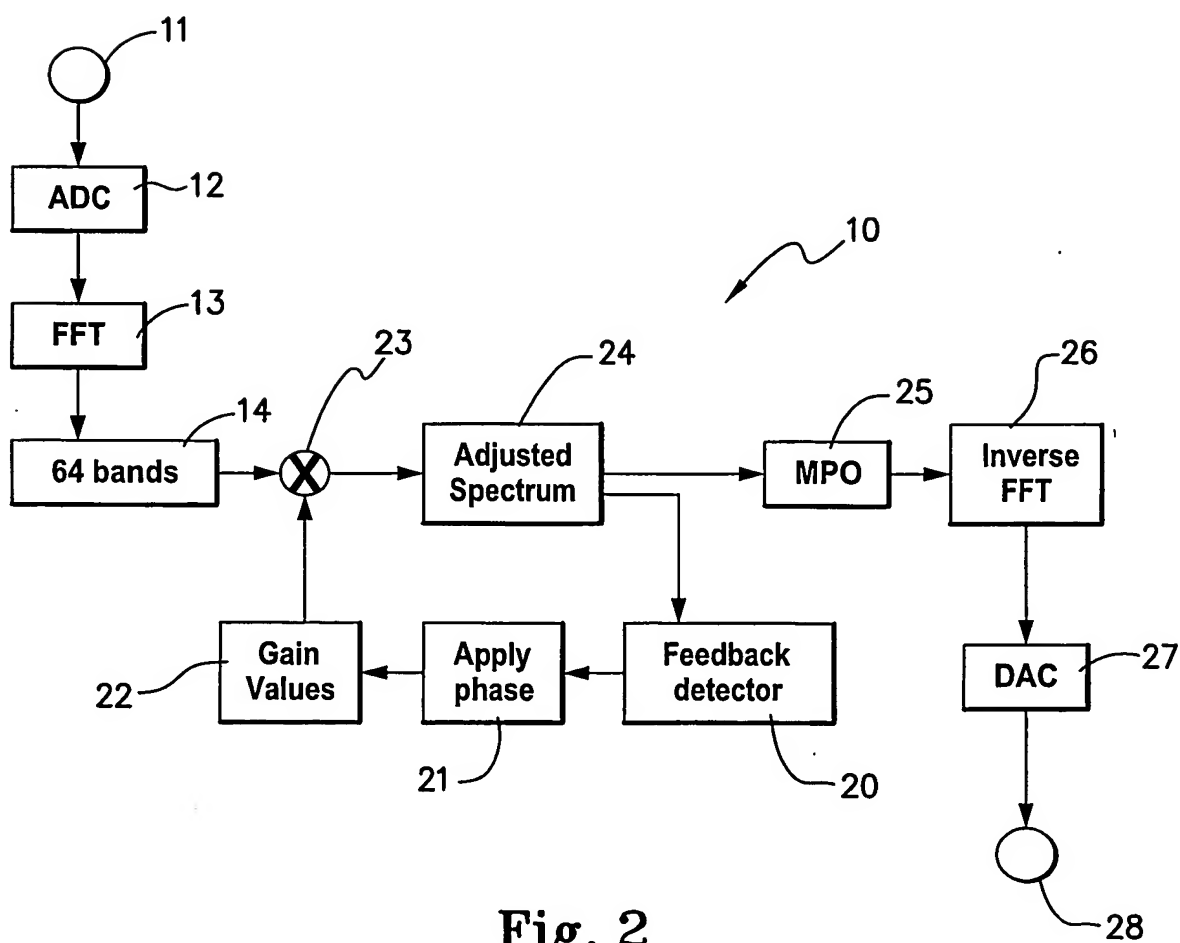


Fig. 2

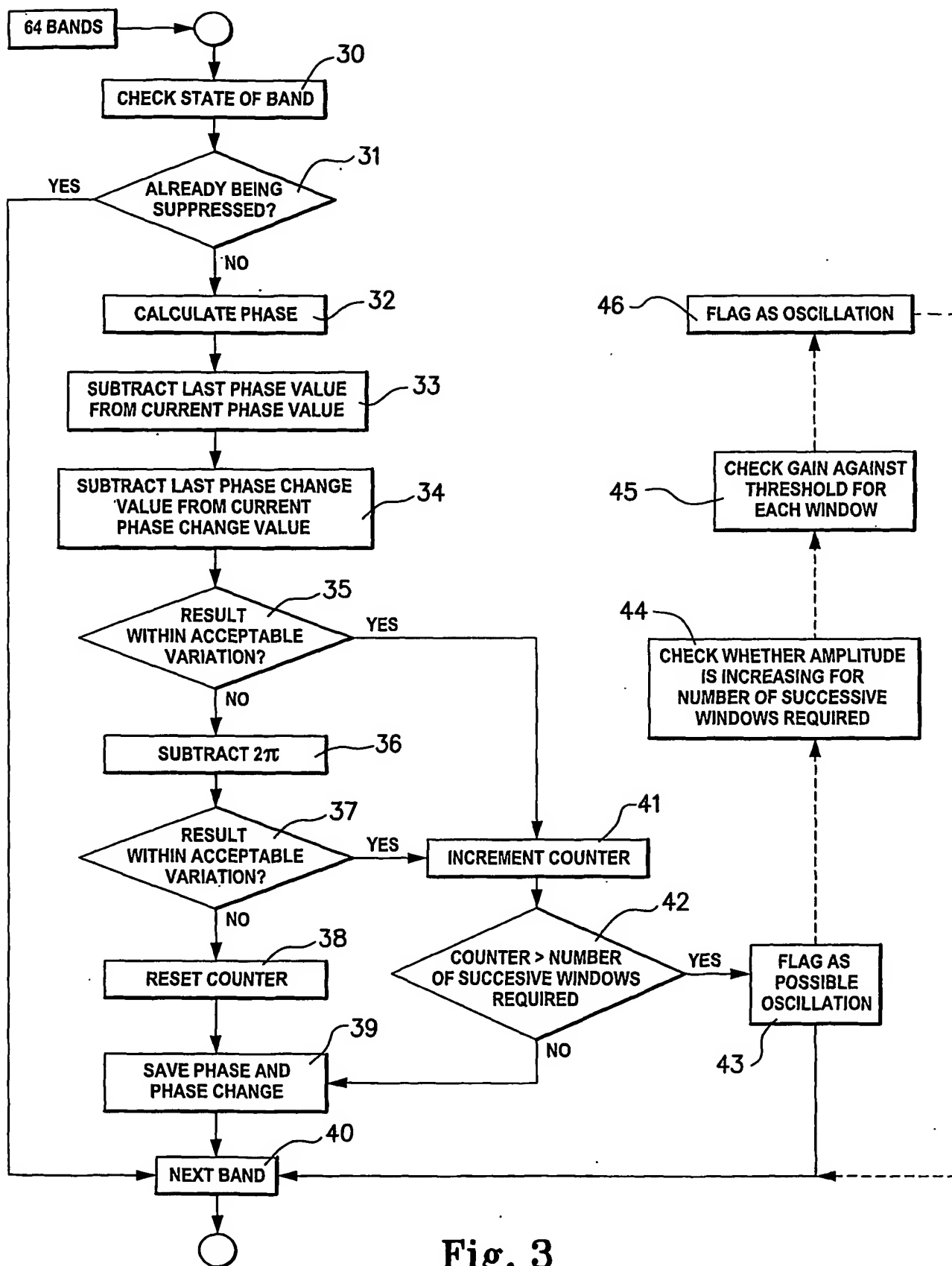


Fig. 3

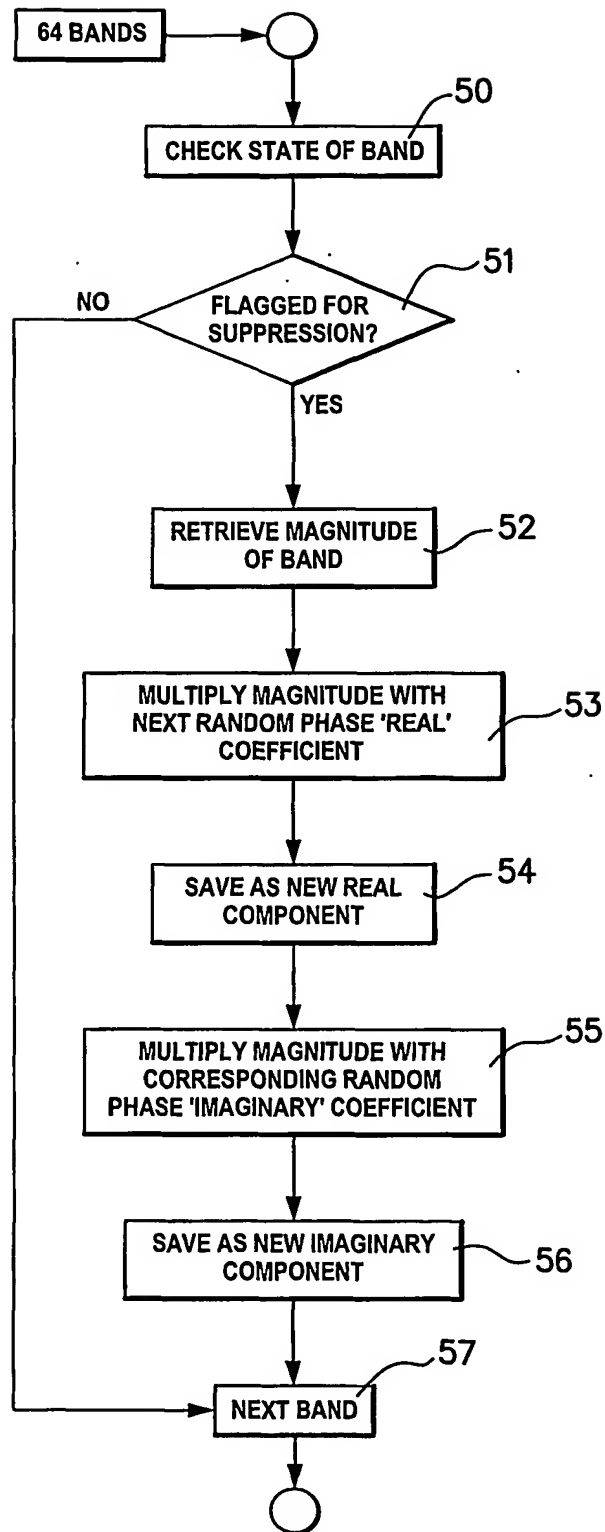


Fig. 4

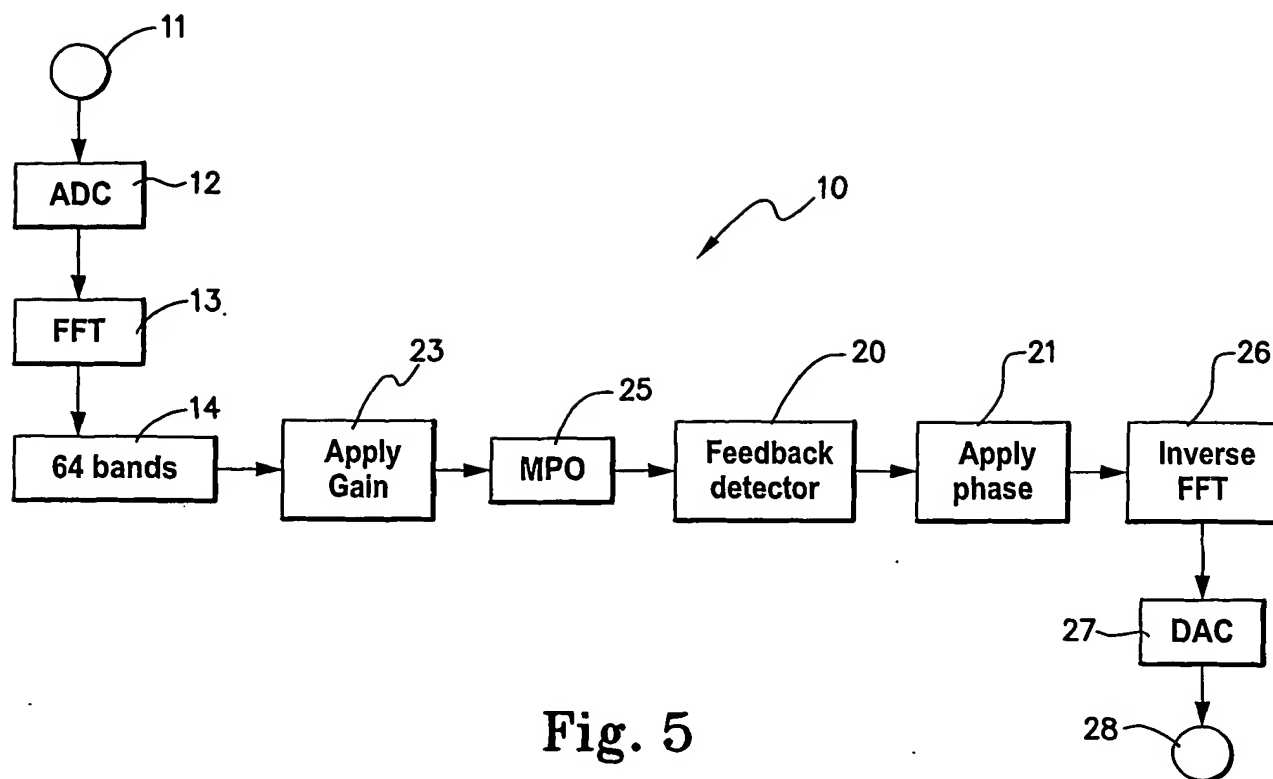


Fig. 5

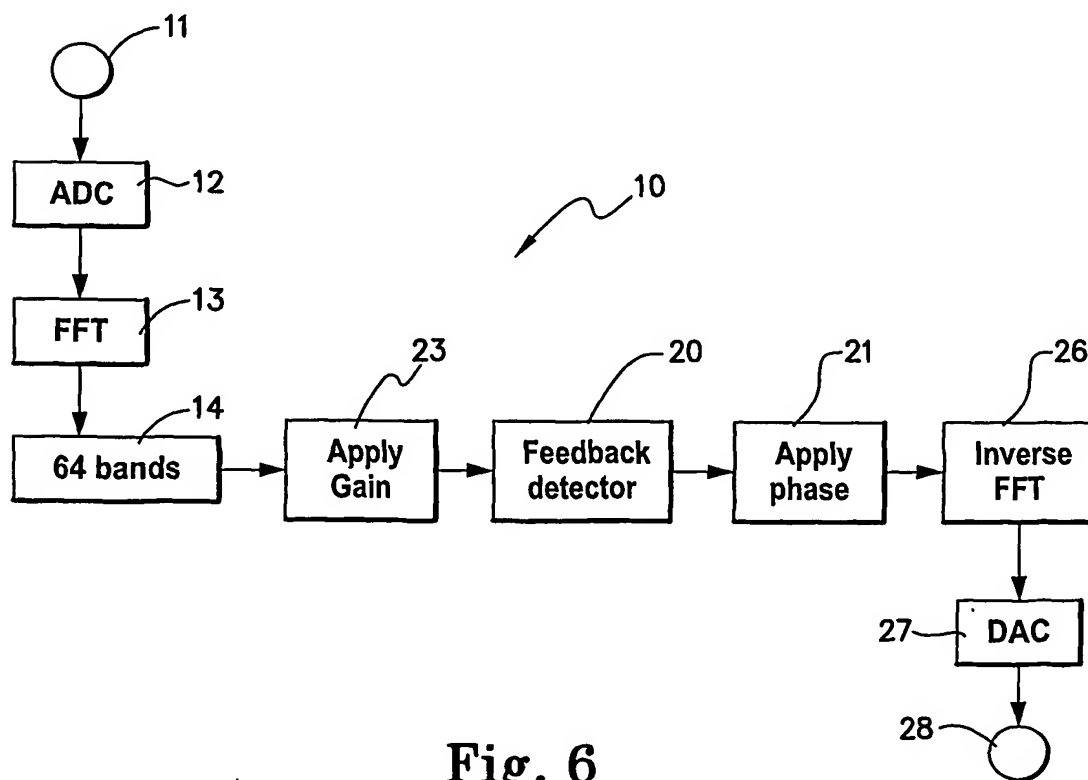


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2004/000701

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. ⁷: **H04R 25/00**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT, USPTO, INSPEC: signal, oscillation, feedback, time, duration, frequency, phase, domain, measure, detect, change, convert and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6498858B2 (KATES), 24 December 2002 whole document	
A	US 6434246B1 (KATES et al), 13 August 2002 whole document	
A	Wang, R. and Harjani, R., "Acoustic Feedback Cancellation in Hearing Aids", in Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing (Cat. No. 92CH3252-4), Minneapolis, USA, April 1993, pp137-140 whole document	
A	Wang, R. and Harjani, R., "Suppression of Acoustic Oscillations in Hearing Aids Using Minimum Phase Techniques", in Proceedings of the IEEE International Symposium on Circuits and Systems, 1993, pp. 818-821 whole document	

☐ Further documents are listed in the continuation of Box C

☒ See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
6 July 2004

Date of mailing of the international search report
12 JUL 2004

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2004/000701

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	6498858	AU	13123/99	AU	32075/99	AU	32099/99
		AU	71186/96	AU	73658/98	EP	0855129
		EP	0986933	EP	1033063	EP	1068773
		EP	1080606	NO	981561	US	6072884
		US	6097824	US	6104822	US	6219427
		US	6434246	US	2001002930	US	2002094100
		US	2003053647	WO	9714266	WO	9856210
		WO	9926453	WO	9951059	WO	9960822

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX

From the:
INTERNATIONAL SEARCHING AUTHORITY

To:

Allens Arthur Robinson
Patent & Trademark Attorneys
GPO Box 1776Q
MELBOURNE VIC 3001

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21 JUL 2004

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WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43bis.1)

Date of mailing
(day/month/year)

12 JUL 2004

Applicant's or agent's file reference
305343694

FOR FURTHER ACTION

See paragraph 2 below

International application No.

PCT/AU2004/000701

International filing date (day/month/year)

26 May 2004

Priority date (day/month/year)

26 May 2003

International Patent Classification (IPC) or both national classification and IPC

Int. Cl.⁷ H04R 25/00

Applicant

DYNAMIC HEARING PTY LTD et al

1. This opinion contains indications relating to the following items:

- | | | |
|-------------------------------------|--------------|--|
| <input checked="" type="checkbox"/> | Box No. I | Basis of the opinion |
| <input type="checkbox"/> | Box No. II | Priority |
| <input type="checkbox"/> | Box No. III | Non-establishment of opinion with regard to novelty, inventive step and industrial applicability |
| <input type="checkbox"/> | Box No. IV | Lack of unity of invention |
| <input checked="" type="checkbox"/> | Box No. V | Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement |
| <input type="checkbox"/> | Box No. VI | Certain documents cited |
| <input type="checkbox"/> | Box No. VII | Certain defects in the international application |
| <input type="checkbox"/> | Box No. VIII | Certain observations on the international application |

2. FURTHER ACTION

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1bis(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the IPEA/AU

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Box No. I

Basis of the opinion

1. With regard to the language, this opinion has been established on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
☐ This opinion has been established on the basis of a translation from the original language into the following language , which is the language of a translation furnished for the purposes of international search (under Rules 12.3 and 23.1(b)).
2. With regard to any nucleotide and/or amino acid sequence disclosed in the international application and necessary to the claimed invention, this opinion has been established on the basis of:
 - a. type of material
☐ a sequence listing
☐ table(s) related to the sequence listing
 - b. format of material
☐ in written format
☐ in computer readable form
 - c. time of filing/furnishing
☐ contained in the international application as filed.
☐ filed together with the international application in computer readable form.
☐ furnished subsequently to this Authority for the purposes of search.
3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

**WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY**

International application No.

PCT/AU2004/000701

Box No. V **Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims 1 - 30	YES
	Claims	NO
Inventive step (IS)	Claims 1 - 30	YES
	Claims	NO
Industrial applicability (IA)	Claims 1 - 30	YES
	Claims	NO

2. Citations and explanations:

1. Claims 1-30 are novel and involve inventive step because no individual citation or obvious combination of citations teach "the method or apparatus of identifying oscillation in a signal due to feedback comprising of,

- converting the signal at each of a series of successive time windows into frequency domain,
- calculating for each of a plurality of frequency bands the change in signal phase from a time window to subsequent time window, and
- comparing, for some or all of said frequency bands, the results of the calculation step to one or more defined criteria to provide a measure of whether oscillation due to feedback is present in the signal."

2. The invention defined in Claims 1-30 is considered to have industrial applicability.